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Stadiums as power plants

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Abstract

More than ever in its history, the world as a whole shows awareness of its uniqueness in all matters, both those concerning the given reality (nature) and the reality created by man and his social communities. At the same time, issues concerning each human individual, his family, local social communities and close associations are as important as the issues of larger social communities (states, regions) and the human population on a global world level. Namely, the global world is made up of components, so a serious attitude towards them is essential in order to build more complex systems from them. Powerful means of communication, both those that concern the physical movement of people and things (modern land, water and air communications) and those that transmit information (radio, television, internet) have enabled mass (and relatively cheap) communication of people, and modern means of information movement practically instantaneous (online) monitoring of events from any part of the world in any part of the world, including part of the space of the Universe. The great and universal question of the relationship between personal and collective, local (regional) and universal-world, current and all-time (...) was addressed by the author in the book „Great World Exhibitions. Architecture as a forerunner of the future“. The topic covered in this paper is related to the architecture study program, but also to a large number of other studies (sports, art, cultural history, sociology, public health protection, organizational sciences, economics, for example). This work is part of the content of the lecture on the course „Architecture as an Energy System“ which the author gave after the introduction (2003) of the „Bologna Process“ in the teaching at the Faculty of Architecture of the University of Sarajevo.

Keywords: Stadiums, power stations, PV Panels

Introduction

Stadiums are that architectural program that combines the latest technical achievements and reflects the latest trends in design [1, 2, 3, 4, 5, 6]. As modern stadiums are one of the most complex architectural programs on a long scale of issues and problems (from spatial planning, urban planning and design, architectural design, architectural constructions and materialization, construction technology, installation systems), the content of this work includes consideration of 'stadiums as electrical power stations' [3, 7, 8, 9, 10]. The general characteristic of stadiums built at the beginning of the 21st century is an increase in comfort for all participants of events at the stadium: athletes, spectators, judges and competition delegates, media (photojournalists, journalists, commentators), technical control and service personnel. The elementary assumption of the realization of the requirement of control assurance was covering the stadium, partially or completely, that is, treating the stadium as a classic object that should ensure a high level of comfort for its users (thermal comfort, comfort in relation to lighting, acoustic comfort), including that dimension of comfort that we can define as aesthetic and psychological comfort. Raising the level of comfort in stadiums follows the general standard of a society (state), so it is understandable that we see the first examples of serious efforts in this regard in the USA, since the end of the 20th century, then in Canada, Australia, England, Germany, Japan, for example.

At the same time, FIFA and regional football associations are raising the level of requirements that must be met by stadiums in order to be able to host international matches, especially those of the highest rank such as the FIFA World Cup finals, the UEFA Champions League finals, for example [11,12]. In the further development of the planning, design and construction of the stadium, progress can be expected in the design and application of new, highly sophisticated, materials, new constructive systems, new assemblies of the materialization of fence surfaces, including the playground itself [3,10].

2. Solar radiation

All processes and phenomena in the Earth's atmosphere are the result of solar radiation. Architecture is interested in the total amount of solar radiation that falls on a certain surface. We will briefly explain the path from the generation of radiation to its impact on the observed surface. The Sun is the closest star to the Earth. Its size is 13906×10^5 to 1792×10^6 m in diameter (109 times larger than the diameter of the Earth). Its mass is 331950 times greater than the mass of the Earth. The main components of the Sun are: hydrogen (50%), helium (40%), and various elements (oxygen, manganese,

nitrogen, silicon, carbon, iron...) [6,13,14]. Due to the extremely high pressure (about 13.3×10^9 kPa), the density of the Sun's core is very high (about 95000 kg/m^3). The sun is, in fact, a natural thermonuclear reactor in which the process of fission of light hydrogen atoms into heavier helium atoms takes place. At a temperature of 16×10^6 °C, every second 6×10^{11} kg of hydrogen is converted into 596×10^9 kg of helium. According to Einstein's law of equivalence of matter and energy ($E = mc^2$), the difference of 4×10^9 kg is converted into energy, which means 3.6×10^{26} W. This energy is transmitted into space¹ in the form of electromagnetic radiation, where only $\frac{1}{2}$ part of it reaches the Earth, about 1.8×10^{17} W. If we were to reduce the power of solar radiation reaching the upper surface of Zelja's atmosphere to a unit of surface area, we would obtain the value of specific solar radiation known as the solar constant. It is 1355 W/m^2 . (The annual flow of daily sums of solar radiation on the upper surface of the atmosphere is shown in Figure 1 and Figure 2. However, a smaller amount of energy will fall on the Earth's surface than the one mentioned, and how much it will be depends on a number of factors that we mentioned earlier (Figure 3) [6,13,14].

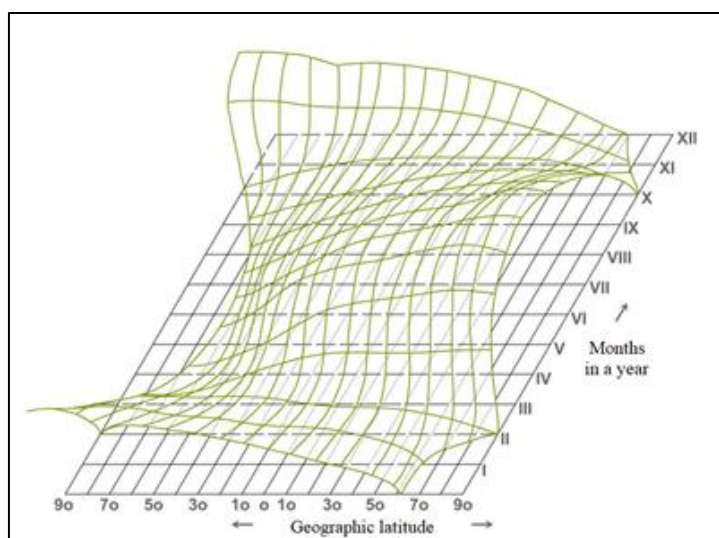


Fig 1: Annual flow of daily sums of solar radiation on the upper surface of the atmosphere (according to V. M. Devis) [6]

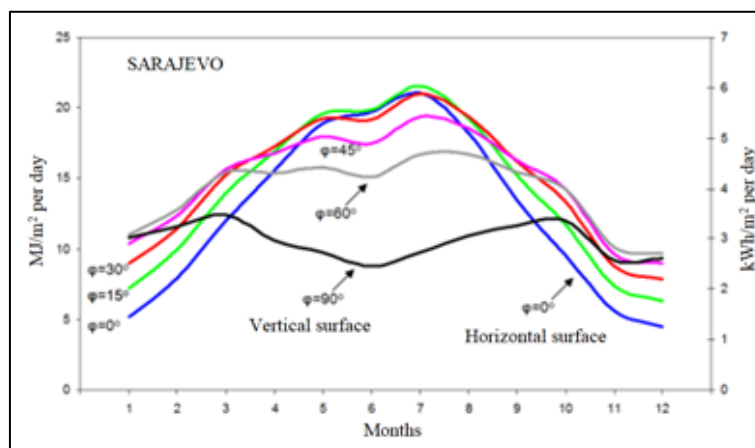
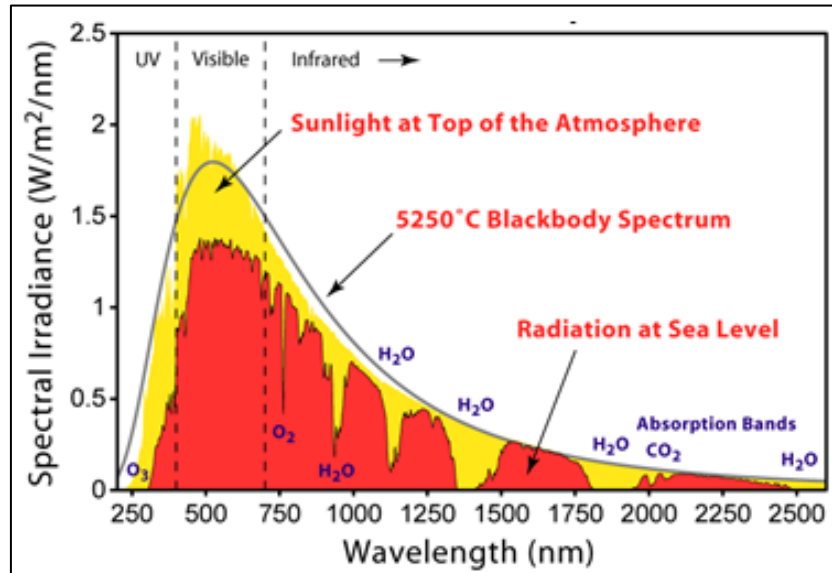


Fig 2: Irradiated solar energy on a horizontal and inclined, south-oriented surface for the city of Sarajevo [17]

¹ In addition to electromagnetic radiation, the Sun also emits corpuscular radiation (protons or electrons) into the Cosmos; their speed is 400-2000 km/s, and their energy is about 10 million times less than the energy of electromagnetic radiation. This radiation causes ionization in the atmosphere, and the aurora borealis is its direct consequence. However, this

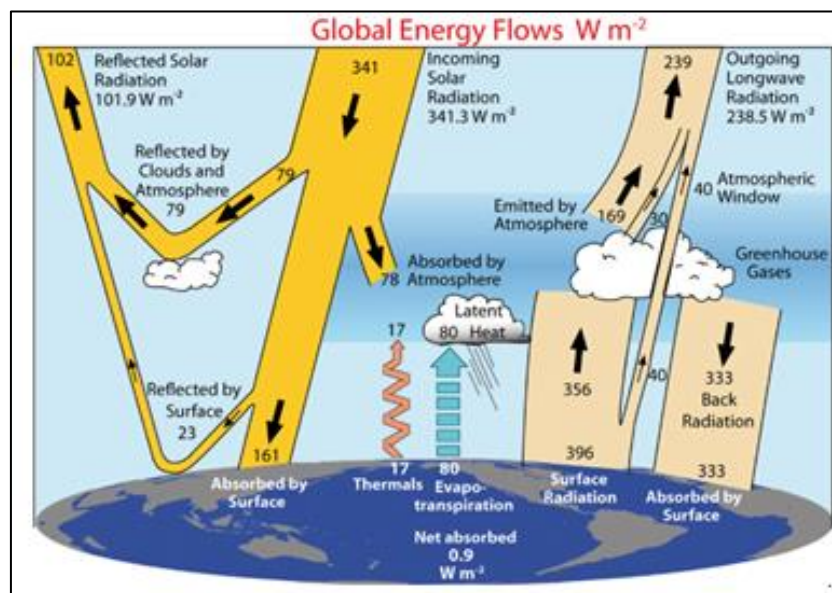
power is about 100,000 times greater than the power of all power plants in the world (data for 1984), or 30,000 times greater than the power of all power plants in the world (data for 2015) if they were to work at full capacity. There are an estimated 62,500 power plants operating worldwide, with a total installed generation capacity of more than 6,000 gigawatts (GW) in 2015 [15].



Source: https://www.researchgate.net/figure/The-solar-radiation-at-the-TOA-and-at-surface-of-the-Earth-after-passing-through-the_fig3_283455091, Accessed: July 20, 2023.

Fig 3: Solar radiation after passing through the atmosphere

The general radiation balance (short-wave and long-wave) is shown in Figure 4.



Source: <https://climataalk.org/2020/12/27/earth-radiation-balance/>, Accessed: July 22, 2023.

Fig 4: Global energy budget for the time period of March 2000 to May 2004. All numbers are in W/m^2 taken from Trenberth *et al.* 2009

Solar radiation falls on the Earth's surface (G) as direct (S) and diffuse (D), whereby diffuse radiation is part of the total radiation resulting from the action of the atmosphere (as a transparent curtain). When the sun's radiation (G) hits the Earth's surface, a part (R) will be reflected and returned to the atmosphere. That reflected part depends on the character of the surface. (Here we call it albedo (a), and it represents the ratio of reflected to incident radiation flux). Thus, the balance of incident and reflected radiation will have values ^[6,13,14]:

$$Q_k = G - R, \text{ or} \\ Q_k = G - a G$$

The value of the mean daily sums of direct solar radiation (in

kJ) on a horizontal surface (1 m^2) are given in Table 1. Obviously, it is a function of the Earth's rotation and revolution ^[6, 13, 14].

Table 1: Mean daily sums of direct solar radiation in kJ on a horizontal surface of 1 m^2 under clear skies (according to Perl) ^[6,13]

North latitude	0°	15°	30°	45°	50°	60°	75°
March	22150	22818	20180	15365	12979	10048	3559
June	20306	23739	26167	26167	24492	26251	26670
September	23027	22609	20515	17375	14654	12351	6490
December	19887	16747	11304	5334	2303	126	0

If, in addition to rotation and revolution, the influence of atmospheric characteristics is added, the radiation value will

be significantly reduced, Table 2.

Table 2: Daily sums of direct solar radiation in kJ on a horizontal surface of 1 m² in a plain with real average cloudiness ^[6,13]

Sjeverna g. širina	0-10°	10-20°	20-30°	30-40°	40-50°	50-60°	60-70°	70-80°
zima	10132	11890	10084	5150	2596	1465	(335)	-
proljeće, jesen	19467	12896	13188	10886	7536	5192	3308	1842
ljetno	8457	8211	14444	16831	12560	9420	8374	6280

Table 3 gives an overview of diffuse radiation (in kJ) on a horizontal surface (1m²) as a function of the Earth's rotation and revolution, cloudiness and altitude ^[6,13,14].

Table 3: Daily sums of diffuse radiation in kJ on a horizontal surface of 1 m² at different cloud cover ^[6,13]

Elevation	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Cloudiness 0/10												
200	1340	1842	2596	3349	3894	4145	3977	3601	2805	2177	1507	1214
1000	1172	1633	2261	2931	3349	3559	3517	3098	2512	1884	381	1047
Cloudiness 2/10												
200	1800	2721	4103	5652	7076	7369	7327	5861	4396	3349	1884	1549
1000	1717	2638	3852	5924	6154	6448	6028	5066	3852	2899	1884	1465
Cloudiness 4/10												
200	2261	3433	4857	6699	9022	9420	8876	7369	5443	3852	2261	1800
1000	2261	3642	5108	6699	8625	8960	8332	6824	5150	3768	2386	1884
Cloudiness 6/10												
200	2386	3684	5443	7285	10467	10927	10425	8457	6280	4270	2554	1968
1000	2763	4354	6113	8080	10718	10802	10132	8415	6238	4438	2847	2135
Cloudiness 8/10												
200	2177	3559	5150	7178	9965	10467	9839	7955	5652	4019	2428	1758
1000	2931	4689	6490	8499	10718	11221	10383	8918	6531	4940	3098	2344
Cloudiness 10/10												
200	1675	2386	3517	4731	6196	6490	6113	5024	3684	2721	1675	1256
1000	2428	3559	5024	6615	8374	8583	7871	6490	4773	3475	2177	1507

The value of the total radiation (G) in kJ/m² of the horizontal surface given as a function of latitude and characteristics of the atmosphere are shown in Table 4 ^[6,13,14,15,16].

Table 4: Mean daily sums of global radiation in the plain, in kJ, on a clear day (cloudiness o/10 and actual cloudiness (i/10), according to long-term values ^[6,13]

Geographic latitude	0-10°	10-20°	20-30°	30-40°	40-50°	50-60°	60-70°	70-80°
Winter (January)								
o/10	24325	22064	18087	13356	8248	4899	(1089)	-
i/10	20013	19427	16915	10844	6615	3642	(879)	-
March and September (average value)								
o/10	28177	27549	25372	22860	19510	15575	11388	5945
i/10	21604	22776	21562	18548	14654	11394	8080	4940
Summer (July)								
o/10	27089	29308	30940	31401	30229	29391	29768	30145
i/10	20390	21436	25665	27088	23655	20515	19678	18003

Since the ADS consists of fence surfaces that can be horizontal, vertical and in a combination of these two basic positions, then differently oriented with respect to the sides of the world, then it is clear that, depending on their position, they will be differently exposed to solar radiation ^[17] ². The flux of solar radiation reaching the surface in question significantly affects the flows of matter and energy through

the enclosure surfaces of the ADS, as well as other phenomena that can be manifested in various ways: mechanical (temperature expansion), biophysical-chemical (development of microorganisms), biochemical (certain physiological processes of plants)... Therefore, knowledge of the solar radiation reaching its borders is of elementary importance for architecture (Figure 5).

² Despite the fact that Bosnia and Herzegovina belongs to the countries of Europe with significant solar irradiation, the use of solar energy can be considered insignificant compared to EU countries. The natural potential of solar energy in Bosnia and Herzegovina amounts to 67.2 PWh per year, assuming that every day of the year, an average of 3.6 kWh of radiant energy falls on each square meter of the horizontal surface. This value many times

exceeds the total energy needs of Bosnia and Herzegovina. If 2% of the total territory of Bosnia and Herzegovina were covered with solar collectors with an average annual efficiency of 50% and PV modules with an average annual efficiency of 10%, then the total technical potential of Bosnia and Herzegovina would amount to 500 TWh (1800 PJ) ^[17].

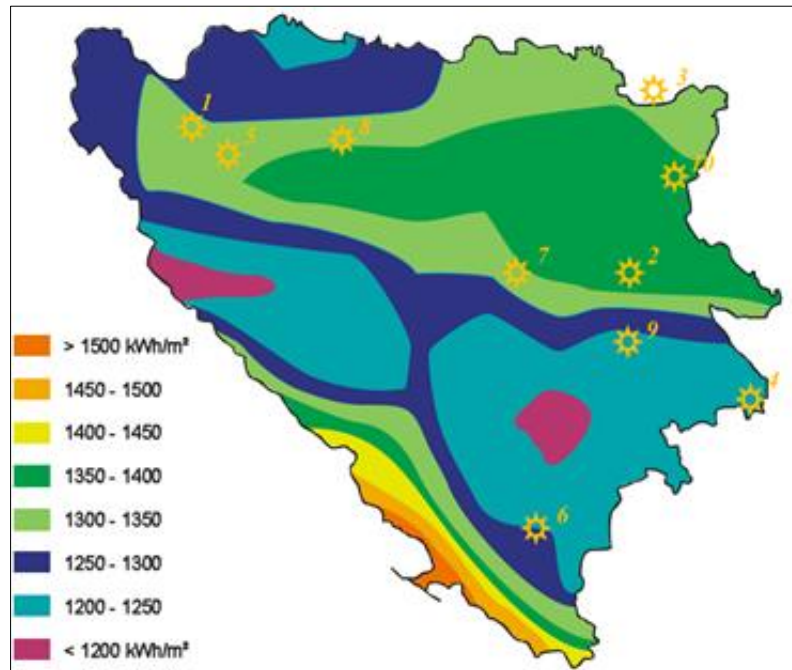


Fig 5: Average annual values of total solar radiation on the horizontal surface for Bosnia and Herzegovina ($\text{kWh/m}^2 \text{ year}$)^[17]

3. Stadiums as power stations

The fact that stadiums are physically large-sized structures (megastructures), that they 'occupy' large areas³, since 1995 there have been design tendencies to create stadiums and their surroundings in the 'field of clean energy production' (on the basis of adequate use of solar radiation, wind and geothermal energy, in the first place)^[3]. We can also expect solutions where the stadiums will have an even more complex structure that will include issues of relationships with nature (plant and animal life). It is also expected that the roof of the stadium (as well as the high space below it and above the playing field) will receive new functions (such as promenades, viewpoints...). The organization that gave a strong impetus to the creation of stadiums as highly energy-efficient structures is the Fédération Internationale de Football Association (FIFA). One of the main drivers for the integration of solar energy into the infrastructure of European stadiums, a concept also called Solar Stadiums, was when FIFA launched the "Green Goal" program as a way to concretely solve the environmental problem. The program was created in 2003, but was presented for the first time only at the 2006 FIFA World Cup in Germany and the 2008 UEFA (Union of European Football Associations) Championship in Switzerland. Sport, due to its ability to reach a huge number of fans around the world, has long been an important platform for promoting values. Globally, the concepts of sustainability and energy efficiency have recently become the subject of

increasing focus. An increasing number of sports fields have started using solar energy in an attempt to improve the sustainable profile of their electricity production. In many cases, the 'solarisation' of stadiums and other sports facilities has been achieved through broad initiatives. One of the biggest initiatives of this kind was the decision of the International Olympic Committee (IOC) to include environmental protection measures (Green programs - the "third pillar of the Olympic Games") as one of the conditions for a successful bid to host the Games. PV systems and heat collectors are popular renewable energy technologies used in both Olympic stadiums and supporting facilities.

The first football stadium in the world where PV panels (which generate electricity from solar radiation) have been installed is Schwarzwald-Stadion in Freiburg, Baden-Württemberg, Germany⁴. In 1995, PV panels generating 259 kWp (Figures 8,9)⁵ were installed on the roof of the stadium. Major solar companies such as Yingli Solar and Jinko Solar have profiled themselves as football sponsors, but one of the most compelling manufacturers is the panels on top of the stadium. During the 2014 World Cup in Brazil, 5 of the 12 stadiums were solar-powered stadiums (and another 1 solar-powered stadium was used in qualifying matches). The holding of the World Cup in Brazil (2014) resulted in the construction of a large number of new stadiums and the reconstruction of other stadiums. In almost all cases, the installation of PV panels on the roof of the stadium was widespread (Figures 6,7)⁶. Several stadiums in the

³ Taiwan National Stadium, Kaohsiung, Taiwan, which was designed by the Japanese architect Toyo Ito (2009), has 8,844 PV-panels on its roof, the total area of which is 14,155 m^2 . These panels generate 1.14 GWh of electricity annually.

⁴ In Germany, there are several stadiums where PV panels are installed. Weser stadium in Bremen (PV panels installed in 2011): 200,000 cells generate 1,270 kWp

Signal Iduna Park in Dortmund (PV panels installed in 2011): 3,000 PV panels generate 924 kWp

Steigerwaldstadion in Erfurt (PV panels installed 2016): PV panels generate 724 kWp

⁵ kWp is the peak power of the PV system or panel. Solar panel systems are rated in peak kilowatts (kWp), which is the rate at which they generate power at peak efficiency, such as on a sunny afternoon.

⁶ Among the most famous stadiums are:

Estádio Nacional Mané Garrincha in Brasília (PV panels installed 2013):

9,600 PV panels generate 2,500kWp

Minerao in Belo Horizonte (PV panels installed 2014): 6,000 PV panels generate 1,420 kWp

Itaipava Arena Pernambuco in Pernambuco (PV panels installed 2014): 3,650 PV panels generate 1,000 kWp

Fonte Nova Arena in Salvador (PV panels installed in 2014): PV panels generate 500 kWp

Estadio do Maracana in Rio de Janeiro (PV panels installed in 2013): 1,556 PV panels generate 400 kWp

Netherlands have installed PV panels⁷. In various countries around the world, a total of around 50 football stadiums have been installed with PV panels⁸.

The maximum amount of electricity that the system can produce under ideal conditions (known as 'peak sun'). Sometimes called 'rated capacity' or 'rated output', it is taken to be 1000 watts (or 1 kW) of sunlight for every square meter of panel. Most domestic solar panel systems have a capacity between 1 kW and 4 kW.

3.1 Selected examples of stadiums where PV systems have been installed

Estádio Mineirão, Belo Horizonte, Brazil (Geographic coordinates: 19°51'57"S, 43°58'15"W). The stadium was

built in 1963-1965 according to the design of the architects Eduardo Mendes Guimarães Júnior and Caspar Garetto and is protected as a building of historical importance. This stadium became the first of several stadiums in Brazil to be equipped with a PV system roof in preparation for the 2014 FIFA World Cup. Mineirão Stadium in the southeastern city of Belo Horizonte, originally built in 1965. With 6,000 solar panels, Mineirão is the first World Cup stadium to be powered by solar energy. The installed capacity of the power plant of 1,600 megawatt hours per year (1.4 MW) is enough to power 1,200 households. Since it is not possible to store all the energy, 10% will be used to power Mineirão and the rest will be transferred to consumers (Figure 6).



Source: <https://www.world-architects.com/en/gmp-architekten-von-gerkan-marg-und-partner-hamburg/project/estadio-mineirao#image-3>

Accessed: July 20, 2023.

Source: <https://www.construction.am/news/446-brazils-mineirao-is-the-first-world-cup-stadium-completely-powered-by-the-sun/>

Accessed: July 20, 2023.

Fig 6: Estádio Mineirão, Belo Horizonte, Brazil

Estádio Nacional de Brasília Mané Garrincha, Brasília (Geographic coordinates: 15°47'0.60"S, 47°53'56.99"W). A brand new national stadium is planned in the heart of Brasília, replacing Mané Garrincha's outdated stadium. The stadium was designed by Castro Mello Arquitetos, gmp architects, schlaich bergermann and partner. The capacity of the stadium is 72,788 seats, and sometimes it is limited to 69,349 seats. The stadium is equipped with a 2.5 MW PV system that will provide enough solar energy to power almost half of the stadium. The construction of the stadium began in May 2010 and ended in mid-2013. Notable features of this stadium include an innovative roof that looks like stretched canvas but incorporates a photocatalytic membrane that breaks down nitrogen oxides, helping to combat pollution from vehicle exhaust. The special roof, which has a retractable center, is semi-transparent, allowing natural light to filter through and

thus reducing interior lighting costs. The stadium will also collect rainwater and use low-flow plumbing fixtures to reduce water consumption. The Estádio Nacional Mané Garrincha in Brasília has around 9,600 photovoltaic panels with a capacity to generate 2.5 MW, which is equivalent to supplying almost 2,000 households per day. The electricity production facility consists of 13,500 m² of photovoltaic panels arranged in a concrete ring of the roof. Since the demand is significantly less than the production, the excess energy is sent to the local utility company for distribution to the city grid. In order to reduce fuel consumption and therefore carbon emissions, the precast concrete sections that will support the upper stands of the stadium were formed on site. The rainwater collection system will help irrigate the landscape and partner with the stadium's low-flow water features to reduce the facility's water footprint (Figure 7).

⁷ Johan Cruyff Arena in Amsterdam (PV panels installed 2014): 4,200 PV panels generate 1,128 kWp

Galgenwaard in Utrecht (PV panels installed 2017): 3,400 PV panels generate 817 kWp

Kyocera Stadium in The Hague (PV panels installed 2014): 2,900 PV panels generate 725 kWp

Euroborg in Groningen (PV panels installed 2014): 1,100 PV panels generate 273 kWp

AFAS Stadium in Alkmaar (PV panels installed in 2015): 1,725 PV panels generate 245 kWp

⁸ Switzerland: Stade de Suisse in Bern (PV panels installed 2005): 8,000 PV panels generate 1,350 kWp

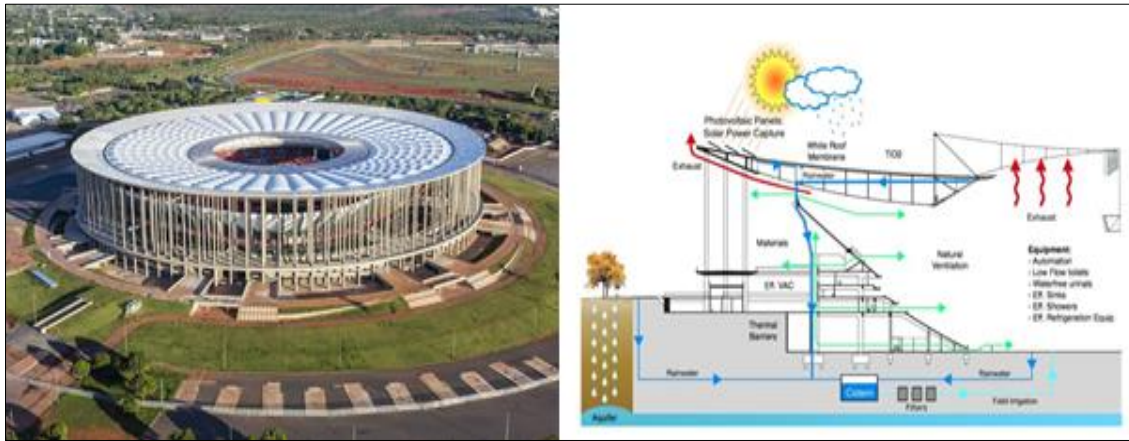
USA: Rio Tinto Stadium in Sandy, Utah (PV panels installed in 2015): 6,500 PV panels generate 2,020 kWp

Turkey: Antalya Arena in Antalya (PV panels installed in 2015): 5,600 PV panels generate 1,400 kWp

France: Allianz Riviera in Nice (PV panels installed 2013): 4,000 PV panels generate 1,342 kWp

Italy: Bentegodi Stadium in Verona (PV panels installed in 2009): 13,300 PV panels generate 1,000 kWp

Costa Rica: Estadio Alejandro Morera Soto in Alajuela (PV panels installed in 2015): 864 PV panels generate 260 kWp



Source: http://stadiumdb.com/tournaments/world_cup/2014/estadio_nacional, Accessed: July 20, 2023.

Source: <https://inhabitat.com/brasil-remodeled-national-stadium-will-be-a-solar-showcase-for-the-2014-world-cup/brasil-remodeled-national-stadium-will-be-a-solar-showcase-for-the-2014-world-cup-brasil-remodeled-national-stadium-cross-section/>, Accessed: July 20, 2023.

Fig 7: Estádio Nacional de Brasília Mané Garrincha, Brasília

Schwarzwald-Stadion (Dreisamstadion) is the stadium of SC Freiburg, Germany. (Geographic coordinates: 40°48'48.7"N, 74°4'27.7"W). SC Freiburg's success in building an environmentally sustainable stadium serves as an important case for the development of new concepts for understanding environmental initiatives in sports [18]. The stadium uses several sustainable principles: Solar energy (the installed power of PV panels is 259 kWp), green energy storage, charging stations, for example. The new stadium in Freiburg will not only be environmentally friendly – it will also have the capacity to become climate neutral. Located at the foot of the Black Forest, Freiburg is the greenest - and sunniest - city in Germany. Its long-standing commitment to sustainability is reflected in the home of Bundesliga side SC Freiburg. Schwarzwald-Stadion with 24,000 seats is the first German football stadium to use solar panels. Since solar panels were

installed on the roofs in 1993, the stadium has produced 250,000 kWh per year, powering the stadium and feeding any excess back into the local grid. Drawing on the world-renowned green ethos of the Baden-Württemberg city is the new Freiburg Stadium, which is due to open later in 2021. Die Breisgauer's forward-thinking home will integrate solar panels on its roof and recycle energy generated from a nearby production plant to heat the stadium. The current Schwarzwald-Stadion has 3 stands covered with photovoltaic panels and supplies around 250,000 kWh (Figures 8,9). The solar facility is the world's third largest photovoltaic system on a football stadium after the 4.2 MW system installed on the roof of the Ali Sami Yen Nef Stadium Sports Complex in Istanbul, Turkey, and the 2.5 MW array installed on the roof of the Mané Garrincha National Stadium in Brasília, Brazil.



Source: <https://www.goalzz.com/?stadium=2253>, Accessed: July 21, 2023.

Fig 8: Schwarzwald-Stadion (Dreisamstadion), Freiburg, Germany



Source: <https://renewablesnow.com/news/football-club-sc-freiburg-plans-worlds-largest-pv-system-on-stadium-773857/>

Accessed: July 21, 2023.

Source: <https://www.besoccer.com/stadium/schwarzwald-stadion-188>, Accessed: July 21, 2023.

Fig 9: (New) Schwarzwald-Stadion (Dreisamstadion), Freiburg, Germany

Weser Stadium in Bremen, Germany (Geographic coordinates: 53°3'59.02"N, 8°50'15.46"E). The Weserstadion is picturesquely situated on the north bank of the river Weser and is surrounded by lush green parks (the name 'Werder' is the regional German word for 'river peninsula'). The stadium is only one kilometer away from the city center. It is the home stadium of the German Bundesliga team Werder Bremen. The stadium originally included an athletics track, but this was partially removed in 2002 when the pitch was sunk by 2.1 meters and the stands on the flats were extended onto the new pitch. This increased the capacity by about 8,000 seats. In 2004, four business towers were built behind the north stand. These towers offer a restaurant and offices for the club and local companies. Starting in 2008, the stadium was completely renovated. The facade is covered with photovoltaic panels and a new roof was built on top of the old roof supporting structure (the old roof was

demolished). Both ends (east and west) were demolished and rebuilt parallel to the front line of the playing field, removing what remained of the old athletics track. Six thousand square meters of the Weser Stadium with 42,000 seats is covered with photovoltaic cells (that's 200,000 individual cells) for a capacity of 1,270 kW of electricity. The home of the soccer team Werder Bremen can generate more than one megawatt of electricity when the sun is shining. Fans can sign up to buy 1% of their electricity from the stadium, which with its 1.2MW solar capacity produces enough excess energy to power 400-500 homes a year. The better the team, the lower the electricity tariff, although that's not a selling point for Bremen fans this year.

The stadium has also installed a gas micro-turbine to gain additional efficiency in the production of heat and electricity, and hopes to reduce its energy needs by between 12 and 80%, depending on conditions (Figure 10).



Source: <https://www.bremen-tourismus.de/bremen/guide/detail/DEU99999990043905544?lang=en>,

Accessed: July 22, 2023.

Source: <https://www.istockphoto.com/search/2/image?phrase=werder>, Accessed: July 22, 2023.

Fig 10: Weser Stadium in Bremen, Germany

Taiwan National Stadium (Geographic coordinates: 22°42'10"N, 120°17'42"E) was built in 2009 according to the project of the world-famous architect Toyo Ito. The stadium serves not only as a world-class facility for sports and various events, but also as an educational facility. Its urban eco-park is a living classroom open to the community all year round. Its green building is a conduit for teaching people about sustainable development, open for group tours led by volunteers well-versed in the project's green facts. The stadium also demonstrates Taiwan's commitment to renewable and clean energy. The National Stadium is the world's first stadium designed using integrated photovoltaic panels (BIPV). With 8,844 PV modules, it is a 1 MWp system

generating 830,000-900,000 kWh per year, currently the second or third largest solar PV system among stadiums in the world. The system can provide 70% of the stadium complex's electricity needs and offset the emission of approximately 660 tons of carbon dioxide. (As a point of reference, in 2007 the Stade de Suisse in Bern, Switzerland completed the largest rooftop solar PV system among stadiums. With 7,930 PV modules, it's a 1.3 MWp system generating 1.13 million kWh annually).

Taiwan National Stadium's green building measures include:

- Energy-efficient measures such as low-emission double glazing, high-efficiency VAV (variable air volume) systems and VWV (variable water volume) air-

conditioning chillers and high-efficiency lighting.

- Indoor air quality measures such as fresh air intake and low VOC interior finishes.
- Water-saving measures such as low-flow plumbing fixtures (toilets, urinals, faucets and showers).
- Water recycling measure – a gray water system that purifies water from sink taps, shower taps and laundry and recycles it for toilet flushing.
- Water recycling measure – a rainwater harvesting (RWH) system that collects rainwater runoff from the roof for use in irrigation. The RWH storage tanks have a capacity of approximately 3.2 million gallons and if filled to capacity, the amount of water is enough to irrigate the entire landscape for six days. (It rains all year

round in Taiwan).

- Use of recycled content: slag replaces 30-40% of Portland cement in the concrete mix. The slag is sourced locally from China Steel Corporation's own steel mills based in Taiwan (steel slag is a by-product of steel production).
- Use of local materials: All building materials and site materials except the pavement for the track are made in Taiwan.

The multi-layer canopy at the Taiwan National Stadium shows the intricacy of the combination of the spiral frame, free structural elements, BIPV panels and maintenance access (Figures 11,12).



Source: <https://www.pinterest.com/pin/299911656435348203/>, Accessed: July 22, 2023.

Source: <https://gabreport.com/taiwan-national-stadium-sculpted-from-concrete-steel-and-bipv-panels>, Accessed: July 20, 2023.

Fig 11: Taiwan National Stadium

The corrugated roof made of BIPV panels required strategic and careful installation. The 1 MWp solar PV system was

provided by Delta, Taiwan's leading PV solutions provider ().



Source: <https://inhabitat.com/taiwans-solar-stadium-100-powered-by-the-sun/solar-stadium-ed04/>, Accessed: July 23, 2023.

Source: <https://gabreport.com/taiwan-national-stadium-sculpted-from-concrete-steel-and-bipv-panels>, Accessed: July 23, 2023.

Fig 12: Taiwan National Stadium

Stade de Suisse (2005-2020), Wankdorfstadion (2020-present), Bern, Switzerland (Geographic coordinates: 46°57'47.40"N, 7°27'53.40"E) was built in 2005 according to the project of the design company Marazzi Generalunternehmung AG. The stadium is home to BSC Young Boys. The capacity of the stadium is 32,000 visitors (football) and 45,000 (concerts). Solar panels (8,000 of them) cover a total of 12,000 square meters. Although it was overtaken in size by Taiwan's World Games Stadium in 2009,

it still produces more energy than any other. Since its commissioning, the stadium's solar power plant has been transformed into a tourist-technological attraction for the general public (Figure 13). Every year, tens of thousands of people climb up to the panoramic 'sun' room on the roof of the stadium to see how sunlight is converted into electricity. They go up to see the photovoltaic cells that produce 1,350 kWp of electricity per year, enough to power 400 homes. The efficiency rate of the panel is 15%. This means that 15% of

the energy of sunlight is converted into electrical energy. The first phase of the station at the Stade de Suisse was built in 2005 to produce an annual amount of 800,000 kWh. This electricity was sold to private individuals, companies and city authorities. The sale was so successful that it enabled the potential production to increase by more than 450,000 kWh in 2007. Three decisive factors were key to the achievement of the project. First, buyers seemed to be interested in buying solar power, then there was a lot of land available to build a

solar power plant, and finally the football stadium attracted people, which was a good opportunity to introduce people to solar power. In 2005, the Stade de Suisse gained international fame after winning the European Solar Award. In Switzerland, there are three other football stadiums with smaller solar cells on their roofs: St Jakob in Basel (since 2001), Letzigrund in Zurich (since 2008) and SRG Arena in St Gallen (since 2009).



Source: <https://www.swissinfo.ch/eng/solar-stadiums/8693206>, Accessed: July 21, 2023.

Fig 13: Stade de Suisse (2005-2020), Wankdorfstadion (2020-present), Bern, Switzerland

MetLife Stadium, East Rutherford, New Jersey, USA (Geographic coordinates: 40°48'48.7"N, 74°4'27.7"W). The stadium with a capacity of 82,500 seats for spectators was built (2010) according to the design of the '360 Arhitektura' team. The top level of the stadium is surrounded by the NRG Solar Ring™. It consists of 1,350 solar panels and produces electricity on site for MetLife Stadium, including power for

LED lighting (916 LED lamps). Photovoltaic panels integrated into the building (manufactured by Atlantis Energy Systems) generate about 350 kW of energy, almost 25 times the amount needed to power the LED display. In addition to meeting the daily energy needs of the stadium, the energy can illuminate the ring when the sun goes down. All excess energy can be returned to the grid (Figure 14) ^[3,18].



Source: <https://patch.com/new-jersey/across-nj/nj-host-2026-world-cup-matches-metlife-stadium>, Accessed: July 20, 2023.

Source: <https://architizer.com/idea/1255009/>, Accessed: July 20, 2023.

Fig 14: MetLife Stadium, East Rutherford, New Jersey

In addition to football stadiums, other sports facilities are places for installing PV systems (Figure 15). The largest North American 'solar venue', which also holds the title of the

largest solar venue in the world, is the Indianapolis Motor Speedway, home of the Indie 500. The venue is powered by nearly 40,000 solar panels with a capacity of 9,000 kWp.

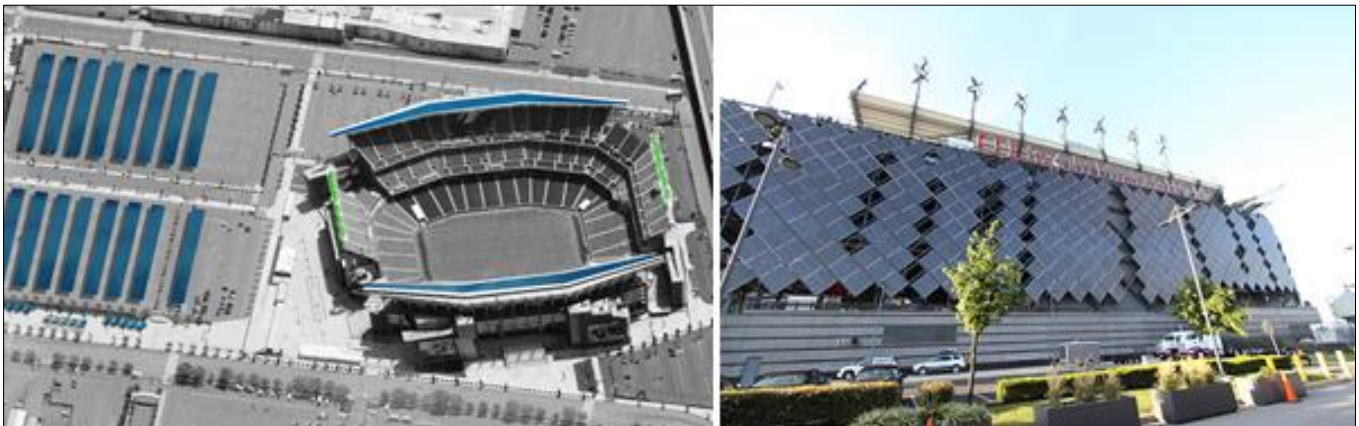


Source: <https://pv-magazine-usa.com/2021/02/23/solar-at-the-speedway-nascar-aims-to-make-racing-more-eco-friendly/> Accessed: July 21, 2023.

Fig 15: Indianapolis Motor Speedway

In second place by the power of installed PV systems is the home of the Philadelphia Eagles, Lincoln Financial Field with a capacity of 3000 kWp (Figure 16). The stadium's renewable energy generation system is also equipped with 14

micro wind turbines and is capable of a combined annual production of more than four times the energy consumed during the home game day season.



Source: <https://www.dlrgroup.com/work/nrg-energy-collaborations/>, Accessed: July 21, 2023.

Source: <https://www.waste360.com/waste-reduction/philadelphia-eagles-sustainability-efforts-soar-new-heights>, Accessed: July 21, 2023.

Fig 16: Philadelphia Eagles, Lincoln Financial Field

In third place is Pocono Raceway located in Pennsylvania with almost 39,960 solar panels (Figure 17). This renewable energy capacity combined with a recycling and tree planting program has made this location one of the most

environmentally conscious tracks in NASCAR. Pocono Raceway started developing its PV system in 2010 and continues to this day⁹.

⁹ The 25-acre, three-megawatt Pocono Raceway Solar Farm currently ranks among the top 10 largest solar-powered sports fields in the world. Pocono Raceway's solar installation consists of 39,960 American-made photovoltaic modules. Pocono Raceway's solar farm generates enough energy to power the track's daily operations and supplies electricity to more than 300 local homes and businesses each year. The Pocono Raceway Solar Farm produced

a total of 37042235 million kilowatt hours (kWh.) The energy produced by the Pocono Raceway Solar Farm is equivalent to 1074224 propane cylinders or approximately 3000421 gallons of gasoline. It is also equivalent to reducing carbon emissions by over 26,190 metric tons, offsetting the carbon dioxide from 666,759 trees, or the greenhouse emissions from 5,658 passenger cars driven during the year.



Source: <https://www.poconoraceway.com/solar-farm-celebrates-10-years-of-producing-clean-and-renewable-energy.html>
 Accessed: July 21, 2023.

Fig 17: Pocono Raceway, Pennsylvania

The first use of PV panels in the world, in cricket stadiums, is seen at the M. Chinnaswamy Mudaliar Stadium in India¹⁰. Cricket is by far the most popular sport in India and the M. Chinnaswamy Stadium in Bangalore is one of the most famous cricket stadiums in the country. On match days, up to 40,000 spectators flock to the stadium, which was built in 1969. With the support of the Green Wicket campaign, Stadium M. Chinnaswamy Mudaliar has now been converted into a 'green' stadium. A modern plant installed on the roof of one of the stands helps to collect up to 35 million liters of rainwater every year, which can be used for sanitary facilities or for watering the playing field. An optimized waste disposal system ensures that the trash left behind by spectators is disposed of in an environmentally friendly way and recycled. A solar system on the roof of the East Stand provides clean energy for the visitor areas and changing rooms. The M. Chinnaswamy Stadium is the world's first solar-powered cricket stadium. The Green Wicket campaign was launched with the aim of encouraging public enthusiasm for water,

energy and waste management issues. The campaign is a joint initiative of the government of the southern Indian state of Karnataka, Karnataka State Cricket Association (KSCA) and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. To achieve its goals, the campaign seeks to capitalize on the immense appeal of India's national sport. As part of the Indian-German cooperation, GIZ supports the campaign on behalf of the Federal Ministry for Economic Cooperation and Development (BMZ). Solar systems like the one at the Bangalore stadium are cost-effective to maintain, and excess power from the roof of the stand can be fed directly into the city's electricity grid. Although the installation costs will be recouped in just four years, the environment is already benefiting as the use of solar energy helps to save 600 tons of CO₂ per year. A 400kW network interactive solar power plant has been installed on the roof of the stadium. By design, this network can easily power the entire stadium's lighting except for the huge high-intensity floodlights (Figure 18).



Source: <https://www.facebook.com/photo/?fbid=501272988796420&set=a.501272968796422>, Accessed: July 21, 2023.

Source: <https://www.thebetterindia.com/22091/chinnaswamy-stadium-worlds-first-solar-powered-cricket-venue/>, Accessed: July 21, 2023.

Fig 18: Stadium M. Chinnaswamy Mudaliar, Bengaluru, Karnataka, India, 1969 (Architects: K P Padmanabha & Associates)

Conclusion

Stadiums are that architectural program that combines the latest technical achievements and reflects the latest trends in design. As modern stadiums are one of the most complex

architectural programs on a long scale of issues and problems (from spatial planning, urban planning and design, architectural design, architectural constructions and materialization, construction technology, installation

¹⁰ Previously known as the Karnataka State Cricket Association Stadium, it was later renamed in honor of Mangalam Chinnaswamy Mudaliar, a lawyer from Mandya and founder of the Mysore State Cricket Association. A water

treatment plant was added in 2016, and an aeration and drainage system was installed by January 2017.

systems), the content of this work includes consideration of 'stadiums as electrical power stations'. The general characteristic of stadiums built at the beginning of the 21st century is an increase in comfort for all participants of events at the stadium: athletes, spectators, judges and competition delegates, media (photojournalists, journalists, commentators), technical control and service personnel. The elementary assumption of the realization of the requirement of control assurance was covering the stadium, partially or completely, that is, treating the stadium as a classic object that should ensure a high level of comfort for its users (thermal comfort, comfort in relation to lighting, acoustic comfort), including that dimension of comfort that we can define as aesthetic and psychological comfort. Raising the level of comfort in stadiums follows the general standard of a society (state), so it is understandable that we see the first examples of serious efforts in this matter in the USA, since the end of the 20th century, then in Canada, Australia, England, Germany, Japan, for example. At the same time, FIFA and regional football associations are raising the level of requirements that must be met by stadiums in order to be able to host international matches, especially those of the highest rank such as the FIFA World Cup finals, the UEFA Champions League finals, for example. In the further development of the planning, design and construction of the stadium, progress can be expected in the design and application of new, highly sophisticated materials, new constructive systems, new assemblies of the materialization of fence surfaces, including the playground itself [3,11,12]. The energy radiated by the Sun (3.6×10^{26} W) also reaches the Earth, only $\frac{1}{2}$ of its billionth part, about 1.8×10^{17} W. However, this power is about 100,000 times greater than the power of all power plants in the world (data for 1984), or 30,000 times greater than the power of all power plants in the world (data for 2015) if they were working at full capacity. There are an estimated 62,500 power plants operating worldwide, with a total installed generation capacity of more than 6,000 gigawatts (GW) in 2015 [15]. The importance of stadiums in the social life of a community, on the one hand, and the great potential of solar energy that reaches the Earth, on the other hand, have contributed to the fact that the design of stadiums in the world occupies an exceptional place in all spheres of life, and from the aspect of architecture, they have become one of the most attractive architectural programs in general, in which architecture opens up new spatial-constructive and aesthetic possibilities, now and in the future [3, 11, 12, 20, 11].

References

1. Hadrovic A. Defining Architectural Space on the Model of the Oriental Style City House in Bosnia and Herzegovina, Serbia, Montenegro, Kosovo and Macedonia. North Charleston, SC, USA: Booksurge, LLC; c2007:8-15.
2. Hadrovic A. Architecture as an Energy System. Sarajevo: Faculty of Architecture, University of Sarajevo; c2017. (in Bosnian)
3. Hadrovic A. Stadiums. Sarajevo: Faculty of Architecture, University of Sarajevo; c2016. (in Bosnian)
4. Hadrovic A. Great World Exhibitions: Architecture as a Forerunner of the Future. Sarajevo: Avicenna; c2015. (in Bosnian)
5. Hadrovic A. New Approach to the Conceptualization and Materialization of Architectural Defined Space. Sarajevo: Faculty of Architecture, University of Sarajevo; c2016. (in Bosnian)
6. Hadrovic A. Architectural Physics. Sarajevo: Acta Architectonica et Urbanistica, Faculty of Architecture, University of Sarajevo; c2010:18-23.
7. Hadrovic A. Architectura in Context. Sarajevo: Acta Architectonica et Urbanistica, Faculty of Architecture, University of Sarajevo; c2011:245-251.
8. Hadrovic A. Graphic Design Cover Books by Professor Ahmet Hadrovic. International Journal of Multidisciplinary Research and Publications (IJMRAP). 2022;4(12):69-86.
9. Hadrovic A. Network of Architecture Roads. Journal of Smart Buildings and Construction Technology. 2022;4(2):1-18.
10. Hadrovic A. Structural Systems in Architecture. North Charleston, SC, USA: Booksurge, LLC; c2009:3.
11. FIFA. Sustainable Building Standards and Tools. Available from: <https://publications.fifa.com/en/sustainability-report/environmental-pillar/sustainable-building/sustainable-building-standards-and-tools/>. Accessed: July 22, c2023.
12. UEFA. UEFA Launches Sustainable Infrastructure Guidelines. Available from: <https://www.uefa.com/returntoplay/news/027b-169a9c3f3499-852e47de9e6a-1000--uefa-launches-sustainable-infrastructure-guidelines/>. Accessed: July 22, c2023.
13. Milosavljevic M. Climatology. Belgrade: Scientific Book; c1985. (in Serbian)
14. Evans M. Housing, Climate and Comfort. Architectural Press; c1980.
15. Global Energy Observatory. Global Power Plant Database. Published on Resource Watch and Google Earth Engine. Available from: <https://datasets.wri.org/dataset/globalpowerplantdatabase>. Accessed; c2023.
16. Trenberth KE, Fasullo JT, Kiehl J. Earth's global energy budget. Bulletin of the American Meteorological Society. 2009;90:311-324. doi.org/10.1175/200BAMS2634.1.
17. Lulic H, Kulic F, Metovic S. ADEG - Advanced energy prices. As part of the REPowerEU plan, the Commission adopted the EU Solar Energy Strategy in May 2022, which identifies remaining barriers and challenges in the solar energy sector and outlines initiatives to overcome them and accelerate the deployment of solar technologies. It aims to install more than 320 GW of solar PV by 2025 and almost 600 GW by 2030. Alongside the plan, the Commission has also presented a series of initiatives on permitting renewable energy projects, reflected in the political agreement to revise the Renewable Energy Directive (2009/28/EC). These new legal provisions will contribute to the acceleration of the application of solar energy in the EU.

¹¹ Solar energy is the fastest growing energy source in the EU. In 2021, the EU solar PV market grew by 1825.7 GW, for a total installed capacity of 162 GW, while 5.7% of total EU electricity generation came from solar energy. Solar energy is cheap, clean, modular and flexible. The cost of solar energy has decreased by 82% over the decade 2010-2020, making it the most competitive source of electricity in many parts of the EU. The European Green Deal and the REPowerEU plan have made solar energy an integral part of the EU's clean energy transition. Its accelerated implementation contributes to reducing the EU's dependence on imported fossil fuels. In addition, solar energy is the most affordable renewable energy source for households and contributes to the protection of consumers from unstable

- Decentralized Energy Generation Systems in Western Balkans. EUFP 6 – Project; c2005:285.
18. Flyvberg B. Case study. In: Denzin NK, Lincoln YS, editors. *The SAGE Handbook of Qualitative Research*. Los Angeles, CA, USA: SAGE; c2011:301-316.
 19. NRG. Solar Power Generation at MetLife Stadium. Available from: <https://static1.squarespace.com/static/5bc8dc6093a6326951300cf4/t/5bff101689858397dbef2767/1543442472565/NRG+NFL+Stadium+Fact+Sheets.pdf>. Accessed: July 20, 2023.
 20. European Commission. Solar Energy. Available from: https://energy.ec.europa.eu/topics/renewable-energy/solar-energy_en. Accessed: July 22; c2023.